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Tide forecasting method based on dynamic weight distribution for operational evaluation

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Abstract: Through analysis of operational evaluation factors for tide forecasting, the relationship between the evaluation factors and the weights of forecasters was examined. A tide forecasting method based on dynamic weight distribution for operational evaluation was developed, and multiple-forecaster synchronous forecasting was realized while avoiding the instability cased by only one forecaster. Weights were distributed to the forecasters according to each one's forecast precision. An evaluation criterion for the professional level of the forecasters was also built. The eligibility rates of forecast results demonstrate the skill of the forecasters and the stability of their forecasts. With the developed tide forecasting method, the precision and reasonableness of tide forecasting are improved. The application of the present method to tide forecasting at the Huangpu Park tidal station demonstrates the validity of the method.
Key words: *tide forecasting method; operational evaluation; dynamic weight distribution; evaluation factor*

1 Introduction

Tide forecasting is an important part of flood forecasting. It is one of the essential non-engineering measures for flood prevention in estuary regions, as well as an important basis for flood prevention decision-making. Much attention both in China and overseas is devoted to improving the precision of flood forecasting. Many numerical forecasting models and a great number of empirical forecasting models have been developed (Liang et al. 2007; Rajasekaran et al. 2006; Wang and Dong 2003; Yi and Wang 2005; Mei et al. 2005; Huang et al. 2003; Lee and Jeng 2002; Lee 2004), including such lumped conceptual hydrological models as the Xin'anjiang model, the Stanford model, the Sacramento model, and the Tank model, and such physically-based distributed hydrological models as SWAT, THALES, HEC, and the new TOPKAPI. The precision of numerical flood forecasting is not satisfactory owing to its complicated model mechanism and parameter calibration procedure. The empirical flood forecasting models are simpler and more applicable than other methods. However, their forecast precision is affected frequently by some subjective factors. Although the interactive forecasting models presently popular integrate the advantages of numerical and empirical flood

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forecasting, they are mainly limited to single-person forecasting. Otherwise, even if many people can forecast at the same time (Liu and Zhang 2004), their forecast results cannot be analyzed comprehensively and automatically, and evaluation of the quality of their forecasts is separate from the forecasting procedure. Comprehensive analysis of flood forecast results and semi-automatic knowledge acquisition, compensating to a certain extent for the deficits of traditional forecasting methods, have been conducted for flood discharge forecasting by introducing the comprehensive fuzzy assessment concept and the interactive knowledge acquisition idea (Jiang et al. 1999). However, this system still only focuses on single-person forecasting. It doesn't address such cases as multiple-forecaster synchronous forecasting, nor does it evaluate the professional level of forecasters. At present, little research has been conducted to obtain the ultimate forecast results by combining the forecast quality evaluation with multiple-forecaster synchronous forecasting. This study has developed a multiple-forecaster synchronous forecasting method based on dynamic weight distribution for operational evaluation, which involves tide forecast quality evaluation.

2 Tide forecasting method based on dynamic weight distribution for operational evaluation

In general, water level forecasting is comprised of two stages: computing for forecasting and comprehensive analysis of forecast results (Jiang et al. 1999). As a kind of water level forecasting, tide forecasting is also comprised of two such stages. The forecast quality relies on the simulation precision of the numerical model or the empirical model and the analysis of forecast results is related closely to the skill of forecasters. In practice, different forecasters have different capabilities. The stability of their forecasting has significant effects on the results. The tide forecasting method based on dynamic weight distribution for operational evaluation just focuses on improving the quality of the whole forecasting group and the stability of the forecasts without regard to the forecasting models used by the forecasters.

2.1 Operational evaluation factors

The evaluation of tide forecast results relates to many factors, including natural factors, research and technology levels, and the forecasters' experience in forecasting. Even for a single station, different factors have different degrees of influence on the tidal level process in various periods. The main factors in evaluations of the forecast results of different forecasters in view of their professional levels generally include tidal level forecast errors, tidal hour forecast errors, and the rate of eligible forecasts. This study evaluated these three factors. While errors in the scope between positive and negative allowable values are considered eligible, absolute errors are used for operational evaluation. A group of operational evaluation factors has been built: $\{a_1, a_2, a_3\}$ = {average absolute error of forecasted tidal level ($\overline{\Delta H}$), average absolute error of forecasted tidal hour ($\overline{\Delta T}$), eligibility rate of tide forecasting (F)}. Weights have been assigned depending on the importance of each factor in the process of practical forecasting, with a sum of 1: $\sum_{j=1}^{3} \alpha_j = 1$ and j = 1, 2, and 3, in which α_1, α_2, and α_3 are the weights corresponding to a_1, a_2, and a_3, respectively.

2.2 Dynamic weight distribution principles based on forecaster operational evaluation

It is assumed that N forecasters simultaneously perform tide forecasting at a tidal station. A weight value R_i corresponds to the forecast results of the ith forecaster in the Kth forecast task. Furthermore, $\sum_{i=1}^{N} R_i = 100$. Therefore, we can form a parameter sequence $\left\{R_i, K_i, \overline{\Delta H_i}, \overline{\Delta T_i}, F_i\right\}$ ($i = 1, 2, \cdots, N$) for the ith forecaster, which consists of a group of forecast and evaluation factors. Forecasted tidal level by the ith forecaster is defined as H_i, forecasted tidal hour as T_i, the corresponding observed tidal level as H_{pr}, the corresponding observed tidal hour as T_{pr}, the absolute error of the forecasted tidal level as $\Delta H_i = \left|H_i - H_{\mathrm{pr}}\right|$, and the absolute error of the forecasted tidal hour as $\Delta T_i = \left|T_i - T_{\mathrm{pr}}\right|$. The greatest permissible tidal level error is $\pm \Delta H_{\max}$, and the greatest permissible tidal hour error is $\pm \Delta T_{\max}$. An initial parameter sequence of forecast and evaluation factors is denoted as $\left\{R_{0i}, K_{0i}, \overline{\Delta H_{0i}}, \overline{\Delta T_{0i}}, F_{0i}\right\}$. A unique initial weight R_{0i} corresponding to each forecaster should be assigned when the method is first used.

The procedure is as follows:

(1) To avoid randomness of forecast results, an initial weight should be distributed to each forecaster before the Kth forecasting depending on each one's forecast precision, eligibility rate, and the weights of all evaluation factors in the latest K-1 synchronous forecast tasks. The weights of forecasters are adjusted automatically based on their accumulated achievement. If the average absolute error of the forecasted tidal level of the ith forecaster in the K-1 forecast tasks that have been completed is defined as $\overline{\Delta H_{0i}}$, the average absolute error of the forecasted tidal hour as $\overline{\Delta T_{0i}}$, and the forecast eligibility rate as F_{0i}, then the initial weight for the ith forecaster is

$$R_{0i} = \frac{\alpha_1 \overline{\Delta H_{0i}}}{\sum_{i=1}^{N} \overline{\Delta H_{0i}}} + \frac{\alpha_2 \overline{\Delta T_{0i}}}{\sum_{i=1}^{N} \overline{\Delta T_{0i}}} + \frac{\alpha_3 F_{0i}}{\sum_{i=1}^{N} F_{0i}} \tag{1}$$

(2) For the Kth forecast task, the parameters of forecast and evaluation factors corresponding to each forecaster change, and forecast frequency, average absolute errors of forecasted tidal level and tidal hour are updated as follows:

$$K_i = K_{0i} + 1 \tag{2}$$

$$\overline{\Delta H_i} = \frac{\overline{\Delta H_{0i}} K_{0i} + \Delta H_i}{K_i} \tag{3}$$

$$\overline{\Delta T_i} = \frac{\overline{\Delta T_{0i}} K_{0i} + \Delta T_i}{K_i} \tag{4}$$

(3) If $|\Delta H_i| \le \Delta H_{\max}$ and $|\Delta T_i| \le \Delta T_{\max}$, then the forecast results of the *i*th forecaster are qualified, and they can be included in the redistribution of the current weight R_i. The number of forecasters with eligible forecast results is *M*. The forecast eligibility rate of the *i*th forecaster is updated:

$$F_i = \left(\frac{K_{0i} F_{0i} + 1}{K_i} \right) \times 100\% \tag{5}$$

If the forecast results of the *i*th forecaster are unqualified, the results cannot be included in the redistribution of the current weight R_i. The number of forecasters with unqualified forecast results is *N*—*M*, and the forecast eligibility rate of the *i*th forecaster is updated:

$$F_i = \left(\frac{K_{0i} F_{0i}}{K_i} \right) \times 100\% \tag{6}$$

(4) To determine the weight scores of evaluation factors for current weight redistribution in the case that *N* forecasters operate synchronously:

In order to ensure that the total weight *R* of *N* forecasters does not change, a certain amount of weight is deducted from the weight of each forecaster and used for weight redistribution. It is assumed that the rate of weight contribution of a forecaster to weight redistribution is lower when his/her historical forecast precision is higher.

If the weight coefficient deducted from the historical weight of the *i*th forecaster is $\beta_i = (\overline{\Delta H_i} / \Delta H_{\max} + \overline{\Delta T_i} / \Delta T_{\max}) / 2$, the sum of weight values of *N* forecasters used for weight redistribution in the *K*th forecast task is $\sum_{i=1}^{N} (\beta_i R_{0i})$. Then, they are proportionally contributed to operational evaluation factors, and the corresponding weights for various operational evaluation factors are $\alpha_{\mathrm{R}j} = \alpha_j \sum_{i=1}^{N} (\beta_i R_{0i})$ (*j*=1, 2, and 3). Therefore, weights of *M* forecasters to be contributed to each operational evaluation factor of the *i*th forecaster with eligible forecasted results are

$$RH_i = \frac{\alpha_{\mathrm{R1}} (\Delta H_{\max} - \Delta H_i)}{M \Delta H_{\max} - \sum_i \Delta H_i} \tag{7}$$

$$RT_i = \frac{\alpha_{\mathrm{R2}} (\Delta T_{\max} - \Delta T_i)}{M \Delta T_{\max} - \sum_i \Delta T_i} \tag{8}$$

$$RF_i = \frac{\alpha_{\mathrm{R3}} F_i}{\sum_i F_i} \tag{9}$$

where RH_i, RT_i, and RF_i represent separate weight scores to be redistributed to the *i*th forecaster based on the three factors of tidal level error, tidal hour error, and forecast eligibility rate.

Then, the total score of weights redistributed to the *i*th forecaster with qualified forecast results in this forecast round is

$$R_i' = RH_i + RT_i + RF_i \tag{10}$$

$N - M$ forecasters whose forecast quality is ineligible have not participated in weight redistribution in the forecast round. Their redistributed weights are

$$R_i' = 0 \tag{11}$$

Therefore, after this forecast round is completed, the weight of each forecaster is updated as follows:

$$R_i = (1 - \beta_i) R_{0i} + R_i' \quad (i = 1, 2, \cdots, N) \tag{12}$$

Consequently, forecast weights of forecasters can be redistributed dynamically based on operational evaluation, and a new forecast and evaluation factor sequence generated, providing a foundation for the next round of forecasting.

(5) The dynamic weight value of each forecaster is obtained by analyzing the dynamic relationship between the forecast and evaluation factors and the weights of the forecasters. The comprehensive forecast results of the forecast round are

$$H = \frac{1}{100} \sum_{i=1}^{N} H_i R_{0i} \tag{13}$$

$$T = \frac{1}{100} \sum_{i=1}^{N} T_i R_{0i} \tag{14}$$

3 Case study

We chose tide forecasting at the Huangpu Park tidal station in Shanghai as an example. It was assumed that there are three forecasters: A, B and C. The corresponding parameters are shown in Table 1 (the maximum tidal level error is ±0.30 m, and the maximum tidal hour error is ±60 min). The forecast results of high tide for the Huangpu Park tidal station and the observed data from June 12, 2007 are shown in Table 2.

Table 1 Initial parameters for forecast and evaluation factors for each forecaster

Forecaster	Forecast weight R_0	Forecast number K_0	Average absolute error		Eligibility rate F_0 (%)
			Tidal level $\overline{\Delta H_0}$ (m)	Tidal hour $\overline{\Delta T_0}$ (min)	
A	34.1	20	0.20	15	90
B	37.8	20	0.15	10	95
C	28.1	12	0.24	20	75

Table 2 Comparison of forecast results with observed data from June 12, 2007

Forecaster	Forecast result		Comprehensive forecast result		Observed data	
	Tidal hour	Tidal level (m)	Tidal hour	Tidal level (m)	Tidal hour	Tidal level (m)
A	22:40	3.76	23:05	3.64	23:00	3.65
B	23:15	3.57				
C	23:05	3.60				

The evaluation department chose the evaluation factor parameters according to their importance during tide forecasting: $\{\alpha_1, \alpha_2, \alpha_3\} = \{40\%, 30\%, 30\%\}$. The results, after analysis with Eqs. (2) through (14), are shown in Table 3.

Table 3 Parameters for evaluation factors in latest forecast evaluation

Forecaster	Weight score for evaluation factor			Redistributed weight R'	Forecast weight R	Forecast number K	Average absolute error		Eligibility rate F (%)
	RH	RT	RF				$\overline{\Delta H}$ (m)	$\overline{\Delta T}$ (min)	
A	4.938	3.676	4.433	13.047	31.70	21	0.196	15	90.5
B	5.718	4.135	4.664	14.517	39.85	21	0.147	10	95.2
C	6.497	5.054	3.767	15.318	28.45	13	0.225	19	76.9

Analysis of these results shows the following features of the forecasting method based on dynamic weight distribution for operational evaluation:

(1) The absolute error of the tidal hour is considered a forecast and evaluation factor. Its weight score is determined according to the agreement of forecasted tidal hour with the observed data within the eligibility scope. While forecasted values are closer to the observed data, the corresponding weight score obtained is larger. The absolute error of the tidal level also shows the same characteristics.

(2) The forecast eligibility rate is used to evaluate the forecast quality and stability of forecasters, and reduce unstable factors of forecast results. For example, in Table 2, although the values forecasted by C are relatively close to the observed values, his/her eligibility rate in historical forecast records is quite low. This suggests that the randomness of the forecast results is quite large. Although the weight scores for average absolute errors of tidal level and tidal hour forecasted by C are higher, the weight score for the eligibility rate in this round is lower even if it has improved. In this way, the instability caused by randomness of forecaster C in future forecasts can be reduced. If the forecast results of forecaster C are stable during a certain period in the future, the distributed weight will be higher and higher along with the improved eligibility rate.

(3) Comprehensive analysis of forecast results reduces the effects of subjective factors and some accidental factors on forecasts to a quite large extent, and makes forecasted data more reasonable. Although it is possible that the ultimate errors of a comprehensive result from a forecast task are larger than those of a certain forecaster, the forecast results integrating experiences and historical forecast precision of multiple forecasters are more objective and reasonable with the increase of forecast number from the perspective of probability theory.

(4) Forecast and evaluation factors can be considered objective criteria for examining and evaluating the skill of forecasters, so as to promote their enthusiasm for work and improve the whole professional level of the forecasting group.

4 Conclusions

Through analysis of operational evaluation factors for tide forecasting, the interactive relationship between evaluation factors and forecaster weights was examined, a tide forecasting method based on dynamic weight distribution for operational evaluation was proposed, and multiple-forecaster synchronous forecasting was realized. Meanwhile, an evaluation criterion for the professional level of forecasters has been built; while the forecasted values of a forecaster are closer to the observed data, the corresponding weight obtained is larger, and the forecast eligibility rates are also used to evaluate the forecast quality and stability of forecasters. In the case of multiple-forecaster synchronous forecasting, a certain amount of weight is deducted from each forecaster according to the latest forecast results and redistributed among them; therefore, their weights are updated after the forecast task. In this way, the instability caused by the randomness of forecasters can be avoided. This method reduces the unstable factors in forecast results and improves the precision and reasonableness of forecasts. However, weight redistribution in the case of asynchronous forecasting should be further studied.

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